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Risk factors for head injury events in professional rugby union: a video analysis of 464 head injury events to inform proposed injury prevention strategies

Ross Tucker,¹ Martin Raftery,¹ Simon Kemp,² James Brown,³ Gordon Fuller,⁴ Ben Hester,¹ Matthew Cross,^{1,5} Ken Quarrie⁶

¹World Rugby, Dublin, Ireland

²Rugby Football Union, Twickenham, UK

³University of Cape Town, Cape Town, South Africa

⁴University of Sheffield, Sheffield, UK

⁵Department for Health, University of Bath, Bath, UK

⁶New Zealand Rugby, Wellington, New Zealand

Correspondence to

Dr Ross Tucker, World Rugby Pty (Ltd), Dublin, Ireland; ross.tucker@mweb.co.za

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ABSTRACT

Objectives The tackle is responsible for the majority of head injuries during rugby union. In order to address head injury risk, risk factors during the tackle must first be identified. This study analysed tackle characteristics in the professional game in order to inform potential interventions.

Methods 464 tackles resulting in a head injury assessment (HIA) were analysed in detail, with tackle type, direction, speed, acceleration, nature of head contact and player body position the characteristics of interest.

Results Propensity to cause an HIA was significantly greater for active shoulder tackles, front-on tackles, high speeder tackles and an accelerating tackler. Head contact between a tackler's head and ball carrier's head or shoulder was significantly more likely to cause an HIA than contact below the level of the shoulder (incident rate ratio (IRR) 4.25, 95% CI 3.38 to 5.35). The tackler experiences the majority (78%) of HIAs when head-to-head contact occurs. An upright tackler was 1.5 times more likely to experience an HIA than a bent at the waist tackler (IRR 1.44, 95% CI 1.18 to 1.76).

Conclusions This study confirms that energy transfer in the tackle is a risk factor for head injury, since direction, type and speed all influence HIA propensity. The study provides evidence that body position and the height of tackles should be a focus for interventions, since lowering height and adopting a bent at the waist body position is associated with reduced risk for both tacklers and ball carriers. To this end, World Rugby has implemented law change based on the present data.

INTRODUCTION

The tackle is the most injurious match event in rugby union, accounting for between 40% and 60% of all match injuries.^{1–4} Among the more common tackle injuries are those to the head, with concussion now the most frequently occurring injury in the professional game.¹ Studies examining the risk factors of head injuries in the sport find that head injuries occurred most frequently during front-on^{5,6} and high tackles.⁶

We have recently investigated the head injury risk during tackles in the male professional game, with 464 out of 611 (76%) analysed head injury assessment (HIA) events from a cohort of 1516 matches occurring during tackles.⁷ Of these, 72% occur to the tackler. Given the growing concern over head

injuries in sport, a focus on the characteristics of tackles that expose players to the highest risk of head injury is warranted. To our knowledge, no large-scale video analysis study has investigated specific risk factors for head injuries during tackles in professional rugby union, although similar studies exist for Rugby League,⁸ Australian football⁹ and American football,¹⁰ with smaller studies in rugby union.¹¹

The aim of the present study is to analyse the tackle in detail, using World Rugby's HIA protocol, to identify head impacts sufficient to cause a player to either be permanently removed from play or to require an off-field assessment. This approach is the critical next step towards injury prevention and necessitates that risk factors for injury be identified so that interventions can be targeted to reduce injury risk.^{12,13}

METHODS

This prospective cohort study was conducted between 2013 and 2015 in six major professional elite rugby union competitions, described previously.⁷

Analysis framework

A tackle was defined as any event where one or more players attempted to stop or impede the ball carrier, irrespective of whether the player was brought to the ground. This distinguishes our definition from that of a tackle in the law, which requires the ball carrier to be held and taken to ground. However, we chose this definition for consistency with previously published research.¹⁴

All cases of tackles resulting in HIA events, as well as a cohort of 3160 tackles not causing injury from 20 representative control matches, were analysed by a single professional rugby video analyst. Where the classification of the tackle was unclear, a second professional rugby analyst was consulted and consensus reached.

The characteristics of the tackle that were coded were defined through consultation with professional rugby coaches and a referee and experienced rugby epidemiology researchers, and drawing from previous studies examining the rugby tackle and injury.^{6,15}

Table 1 summarises the tackle characteristics analysed.



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Table 1 Characteristics of the tackle analysed in this study

Tackle type	
Active shoulder tackle	First contact is with the tackler's shoulder, and the tackler drives or attempts to drive the ball carrier (BC) backwards.
Passive shoulder tackle	First contact is with the tackler's shoulder and the tackler does not drive or attempt to drive the BC back.
Smother tackle	Tackler uses the chest and attempts to wrap both arms around the ball carrier.
Tap tackle	Tackler trips the BC with a hand on the lower limb below the knee.
Lift tackle	Tackler lifts the BC's hips above the BC head.
No arm tackle	Tackler impedes the BC without use of their arms.
High tackle	Tackler makes contact above the BC shoulders, as adjudicated by the on-field referee.
Tackle direction	
Front-on	Tackler makes contact on the front of the BC.
On angle	Tackler makes contact with the BC on an angle.
Side-on	Tackler makes contact with the side of the BC.
Back	Tackler makes contact with the BC from behind.
Accelerating player	
Tackler	Only the tackler accelerates into contact.
Ball carrier	Only the BC accelerates into contact.
Both	Both tackler and BC accelerate into the contact.
Neither	Neither player accelerates into contact.
Tackler and BC speed	
High	Running or sprinting
Low	Walking or jogging
Stationary	Standing still or moving minimally
Tackler and BC body positions	
Upright	The player is standing in an upright position, with the knees only slightly bent and with minimal hip flexion.
Bent at the waist	The player is bent at the waist or crouched.
Falling/diving	The player is in the process of diving or falling to ground at the point of contact.

HIA events

The HIA protocol has been described in more detail previously.¹⁶ For this study, an HIA event was defined as any player entering the HIA protocol at the HIA1 stage, having either (1) displayed criteria 1 signs and therefore been immediately and permanently removed from play, or (2) received an off-field screening assessment irrespective of whether that player subsequently returned to play or was permanently removed from play.

HIA events were collated in a central database as part of World Rugby's HIA process as described previously.⁷

Data analysis

The propensity, in HIA events per 1000 tackles for each tackle characteristic, was calculated by dividing the number of HIA events occurring from that tackle by the total number of that tackle obtained from the control cohort. Incidence is expressed as HIA events per 1000 match hours.

Data are presented as means and 95% CIs. The probability of each tackle characteristic being associated with a player undergoing an HIA was assessed using a Poisson regression with a log link function, using exposure to the characteristic as the offset variable to compare predictor/independent variables. Incident rate ratios (IRRs) were calculated to compare the propensity of two events by expressing the calculated HIA propensity relative to one another. Data were analysed using a standard statistical package (SPSS, Version 24.0), and a conventional type 1 error

rate of 0.05 was used, with statistical significance accepted when the 95% CIs did not overlap.

RESULTS

Overall summary

Four hundred and sixty-four HIA events occurred during tackles, with 335 (72%; CI 68% to 76%) to the tackler and 129 (28%; CI 24% to 32%) to the ball carrier. The overall propensity for HIA events was 1.94 HIAs/1000 tackles, with tacklers experiencing a more than twofold higher incident rate than ball carriers (IRR=2.59, 95% CI 2.12 to 3.18).

Table 2 shows the number of HIA events, the propensity and the incidence of various tackle characteristics to cause an HIA event, along with the proportion of HIAs to the tackler for each of the characteristics.

Tackle type

The three most common legal tackle types—active shoulder, passive shoulder and smother tackles—accounted for 99% (157 out of 158 tackles per match) of match tackles and 93% of tackle-related HIA events.

Active shoulder tackles had a significantly higher HIA event propensity than passive shoulder and smother tackles (IRR=2.07, 95% CI 1.65 to 2.59 for active vs passive shoulder tackle; IRR 2.13, 95% CI 1.69 to 2.68 for active shoulder vs smother tackle; both $p < 0.05$).

Illegal tackles, ruled by the referee, accounted for 25 HIAs. These had a significantly greater propensity than legal tackles (1.84 HIAs/1000 legal tackles vs 65.9 HIAs/1000 illegal tackles; IRR=35.95, 95% CI 24.02 to 53.79), with high tackles having a particularly high risk (237.5 HIAs/1000 high tackles). Propensity could not be calculated for 'No arm' tackles and 'Use of Elbow' tackles because no such events occurred in the control cohort.

Tackle direction

Front-on tackles had a significantly higher propensity and incidence than angled, side-on or tackles from behind (IRR=1.65 (95% CI 1.31 to 2.13), 2.02 (95% CI 1.58 to 2.60) and 1.73 (95% CI 1.20 to 2.50) for propensity for front-on vs angle, side-on and back tackles, respectively).

Acceleration

Propensity was greatest when the tackler accelerated into the tackle (IRR=2.86, 95% CI 2.28 to 3.58 vs ball carrier; IRR=2.34, 95% CI 1.78 to 3.09 vs both; IRR=3.06, 95% CI 2.11 to 4.42 vs neither). Incidence was greatest when the ball carrier accelerated into the tackle, by virtue of the high frequency of this situation (93 events per match compared with 17 for tackler accelerating).

Number of tacklers

Tackles in which three or more tacklers were involved, although rare, were associated with a higher likelihood of HIAs than those with one (IRR=1.67, 95% CI 1.02 to 2.72) or two tacklers (1.86, 95% CI 1.14 to 3.05).

Player speeds

The propensity for various combinations of player speeds is shown in figure 1. The propensity increased significantly as the tackler speed increased (IRR=3.05, 95% CI 2.39 to 3.89, high-speed vs static tackler; IRR=2.39, 95% CI 1.93 to 2.96, high-speed vs low-speed tackler; $p < 0.05$).

For static and low-speed tacklers, propensity increased as the ball carrier speed increased, whereas for high tackler

Original article

Table 2 Head injury assessment (HIA) number, propensity and proportion to tackler for various tackle characteristics

Tackle characteristics	Events per match	HIA number	Propensity (95% CI), HIAs/1000 events	Incidence (95% CI), HIAs/1000 hours	Percentage of HIAs to tackler (95% CI)
Tackle type					
Active shoulder	39	177	2.98 (2.57 to 3.46)	2.92 (2.52 to 3.38)	77 (70 to 82)
Passive shoulder	61	134	1.44 (1.22 to 1.71)	2.21 (1.87 to 2.62)	84 (77 to 90)
Smother tackle	57	120	1.40 (1.17 to 1.68)	1.98 (1.65 to 2.37)	64 (55 to 72)
Tap tackle	1	5	3.66 (1.53 to 8.80)	0.08 (0.03 to 0.20)	100.0
Lift (illegal)	0.05	1	6.60 (0.93 to 46.83)	0.02 (0.00 to 0.12)	0.0
No arms	0	5			0.0
High tackle	0.05	18	237.47 (149.61 to 376.91)	0.30 (0.19 to 0.47)	11.1 (3 to 33)
Use of elbow/forearm	0	1		0.02 (0.00 to 0.12)	0.0
Tackle direction					
Front	61	247	2.67 (2.36 to 3.02)	4.07 (3.60 to 4.61)	67 (61 to 73)
On angle	41	101	1.62 (1.33 to 1.97)	1.67 (1.37 to 2.02)	75 (66 to 83)
Side-on	42	84	1.32 (1.06 to 1.63)	1.39 (1.12 to 1.72)	81 (71 to 88)
Back	14	32	1.54 (1.09 to 2.18)	0.53 (0.37 to 0.75)	78 (61 to 89)
Accelerating player					
Tackler	17	116	4.47 (3.73 to 5.37)	1.91 (1.59 to 2.29)	64 (55 to 72)
Ball carrier	93	221	1.56 (1.37 to 1.79)	3.64 (3.19 to 4.16)	74 (68 to 80)
Both	31	90	1.91 (1.55 to 2.35)	1.48 (1.21 to 1.82)	77 (68 to 85)
Neither	17	37	1.47 (1.06 to 2.02)	0.61 (0.44 to 0.84)	73 (57 to 85)
Number of tacklers					
1	81	246	2.00 (1.77 to 2.27)	4.06 (3.5 to 4.60)	72 (66 to 77)
2	74	201	1.80 (1.57 to 2.06)	3.31 (2.89 to 3.81)	73 (66 to 78)
3 or more	3	17	3.35 (2.08 to 5.38)	0.28 (0.17 to 0.45)	71 (47 to 87)

speeds, propensity decreased as the ball carrier speed increased (IRR=1.82, 95% CI 1.15 to 2.89, static ball carrier vs high-speed ball carrier when tackler is at high speed; [figure 1](#)).

Type of head contact

[Table 3](#) shows the HIA propensity for the tackler as a result of various types of head contact, along with the number of tackler HIA events for each contact. Data are shown for the tackler only, because study resource limitations meant that the control cohort was analysed from the tackler perspective only.

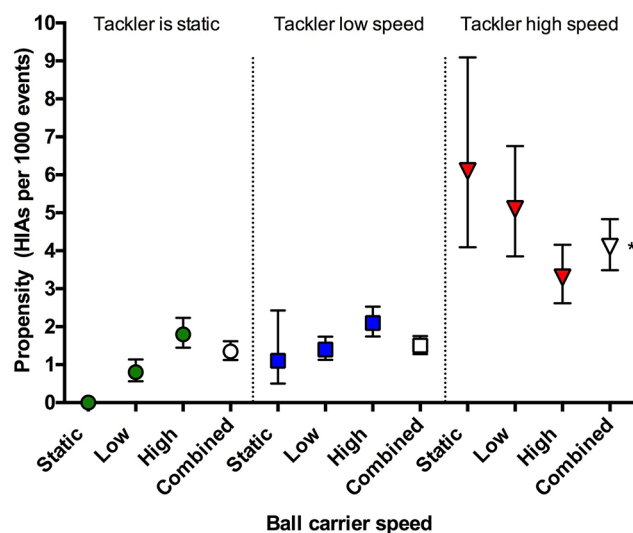


Figure 1 Head injury assessment (HIA) event propensity for combinations of tackler and ball carrier speeds. *Denotes significantly higher than 'Tackler Low Speed' and tackler static conditions.

The greatest propensity occurred for head-to-head contact, followed by head-to-elbow and head-to-knee contact. All types of head contact injured the tackler relatively more often, with the exception of head-to-ground (17% to tackler), whiplash (27% to tackler) and head-to-arm contact (36% to tackler).

When grouped into either 'high contact tackles', being tackler head contact with a ball carrier's head or shoulder (as per by the legal definition of a high tackle), or 'low contact tackles' below the shoulder, the number of HIAs was 130 from high contact (3.75 HIAs/1000 tackles, 95% CI 3.16 to 4.16) and 165 from low contact (0.88, 95% CI 0.76 to 1.03). The IRR for high versus low contact was 4.25 (95% CI 3.38 to

Table 3 Head injury assessment (HIA) number, propensity and proportion to tackler as a result of various types of head contact

	HIAs to tackler	Propensity (95% CI), HIAs/1000 events	Percentage of HIAs to the tackler (95% CI)
Head to head	84	11.30 (9.13 to 14.00)	78 (69 to 85)
Head to elbow	13	6.35 (3.69 to 10.94)	100
Head to knee	19	3.09 (1.97 to 4.85)	61 (44 to 76)
Head to hip	71	1.72 (1.36 to 2.17)	97 (91 to 99)
Head to shoulder	46	1.69 (1.27 to 2.26)	65 (54 to 75)
Head to arm	20	1.37 (0.88 to 2.12)	36 (25 to 50)
Head to lower leg	18	1.36 (0.86 to 2.17)	82 (61 to 93)
Head to ground	1	0.73 (0.10 to 5.20)	17 (3 to 56)
Head to upper body	42	0.46 (0.34 to 0.62)	79 (67 to 88)
Head to upper leg	15	0.43 (0.26 to 0.72)	83 (61 to 94)
Whiplash	3	–	27 (10 to 57)
Head to equipment	0	–	–
Head to hand (fist)	3	–	75.0 (30 to 95)

Table 4 Head injury assessment (HIA) number, propensity and proportion to tackler for tackler and ball carrier body position combinations

Tackler body position	Ball carrier body position	Events per match	HIA number	Propensity (95% CI), HIAs/1000 events	Incidence (95% CI), HIAs/1000 hours	Percentage of HIAs to tackler (95% CI)
Upright	Upright	31	131	2.80 (2.36 to 3.32)	2.16 (1.82 to 2.56)	65 (56 to 73)
	Bent at the waist	9	28	1.99 (1.37 to 2.88)	0.46 (0.32 to 0.67)	46 (30 to 64)
	Falling/diving	0.05	5	65.96 (27.46 to 158.48)	0.08 (0.03 to 0.20)	40 (12 to 77)
Bent at the waist	Upright	33	133	2.64 (2.23 to 3.13)	2.19 (1.85 to 2.60)	87 (80 to 92)
	Bent at the waist	48	83	1.14 (0.92 to 1.41)	1.37 (1.10 to 1.70)	66 (56 to 76)
	Falling/diving	1	17	14.95 (9.29 to 24.05)	0.28 (0.17 to 0.45)	35 (17 to 59)
Diving	Upright	18	40	1.46 (1.07 to 1.99)	0.66 (0.48 to 0.90)	98 (87 to 100)
	Bent at the waist	16	17	0.69 (0.43 to 1.11)	0.28 (0.17 to 0.45)	88 (13 to 53)
	Falling/diving	1	10	4.89 (2.63 to 9.08)	0.16 (0.09 to 0.31)	50 (24 to 76)
Ball carrier body position	Tackler body position	Events per match	HIA number	Propensity (95% CI), HIAs/1000 events	Incidence (95% CI), HIAs/1000 hours	Percentage of HIAs to tackler (95% CI)
Upright	Upright	31	131	2.80 (2.36 to 3.32)	2.16 (1.82 to 2.56)	65 (56 to 73)
	Bent at the waist	33	133	2.64 (2.23 to 3.13)	2.19 (1.85 to 2.60)	87 (80 to 92)
	Falling/diving	18	40	1.46 (1.07 to 1.99)	0.66 (0.48 to 0.90)	98 (87 to 100)
Bent at the waist	Upright	9	28	1.99 (1.37 to 2.88)	0.46 (0.32 to 0.67)	46 (30 to 64)
	Bent at the waist	48	83	1.14 (0.92 to 1.41)	1.37 (1.10 to 1.70)	66 (56 to 76)
	Falling/diving	16	17	0.69 (0.43 to 1.11)	0.28 (0.17 to 0.45)	88 (13 to 53)
Diving	Upright	0.05	5	65.96 (27.46 to 158.48)	0.08 (0.03 to 0.20)	40 (12 to 77)
	Bent at the waist	1	17	14.95 (9.29 to 24.05)	0.28 (0.17 to 0.45)	35 (17 to 59)
	Falling/diving	1	10	4.89 (2.63 to 9.08)	0.16 (0.09 to 0.31)	50 (24 to 76)

5.35). This excludes head contact with the ball carrier's arm, hand or elbow, since these are not necessarily indicative of the area of the ball carrier's body that the tackler is contacting or attempting to make contact with.

Tackler and ball carrier body position

Table 4 shows the HIA propensity and incidence for various tackler and ball carrier body positions, separated into tackler body position in the top panel and ball carrier body position in the bottom panel. For any tackler body position (table 4, top panel), propensity was highest when the ball carrier was falling or diving, and lowest when the ball carrier was bent at the waist. HIA incidence was highest for an upright ball carrier and lowest for a falling/diving ball carrier.

For any ball carrier body position (table 4, bottom panel), the propensity was highest for an upright tackler and lowest when the tackler was falling or diving.

Figure 2 shows the HIA event propensity for tackler and ball carrier body positions when combined for all possible body positions.

Given the relatively low overall incidence of HIAs occurring for falling/diving tacklers and ball carriers (table 4, a specific comparison was made for upright versus bent at the waist body positions for both players. The incident rate was 1.44 (95% CI 1.18 to 1.76) for an upright versus bent at the waist tackler (2.69 HIAs/1000 tackles vs 1.87 HIAs/1000 tackles). The IRR for an upright (2.44 HIAs/1000 tackles) versus bent at the waist ball carrier (1.15 HIAs/1000 tackles) was 2.13 (95% CI 1.73 to 2.62).

DISCUSSION

The present study expands on previous research in this area,^{6 17 18} and is the largest such to date, describing a spectrum of propensities for specific tackle characteristics to result in a head injury event.

We find that the propensity for head injury was greatest for active shoulder tackles, front-on tackles, an accelerating tackler,

more than one tackler, higher speeds, higher impacts and more upright tacklers.

Application of the sequence of prevention model

According to the sequence of prevention model,¹⁹ risk reduction requires first that the extent of the problem be described, something that has been done in numerous injury surveillance studies in various competitions.^{1 2 20} Thereafter, the risk factors for injury must be identified, which was the aim of this study, and then strategies implemented to reduce the risk.

Based on the present data, experts from within rugby, including elite coaches, players and officials, recommended that the game adopt a zero tolerance to head contact. This is to be reinforced by a global awareness programme, the introduction of new tackle

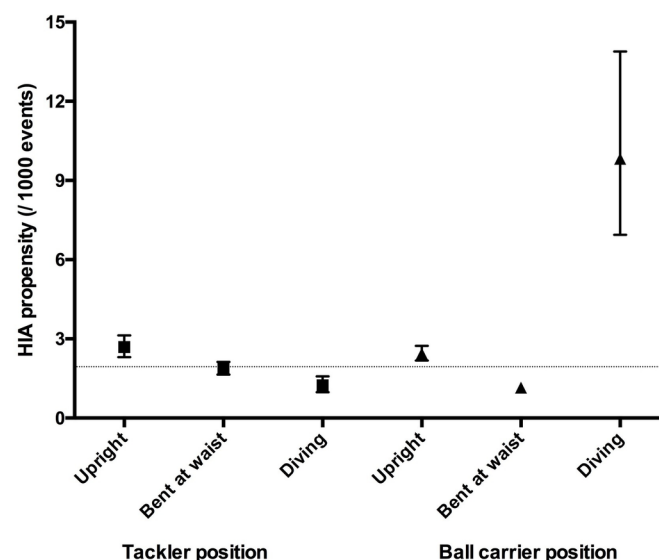


Figure 2 Head injury assessment (HIA) propensity for tackler and ball carrier body position.

Original article

sanction categories (reckless and accidental) and an increase in sanctions for all types of head contact. These interventions are recommended to modify player behaviour and reduce the risk of head injury.²¹ The effects of these adopted changes are currently being monitored.

This study thus represents the application of suggested best-practice injury reduction methods using the public health approach.^{13 19 22} Subsequently, we describe the significant findings of the present research that informed the recommended measures.

Player body position and tackle height

A novel aspect of the present study was the analysis of player body position in the tackle as a risk factor for head injury. This was examined since previous research had established that high tackles were significantly more likely to cause injury, particularly to the ball carrier.⁶

We found that propensity was greatest for an upright tackler and a falling or diving ball carrier, irrespective of the other player's body position (table 4). Given that a falling or diving ball carrier in the tackle is extremely rare (2 events per match, compared with 82 upright and 74 bent at the waist ball carriers per match), the least desired body position in the vast majority of tackles is for both players to be upright.

Taken in conjunction with the finding that high contact types (tackler head to ball carrier head or shoulder) are 4.25 times more likely to cause an HIA than low contact types (below the shoulder), this finding strongly supports the hypothesis that lowering the height of the tackle, enforcing current laws on tackle height and changing the tackler body position from upright to bent at the waist through education or law change may be strategies to consider to prevent injury, as have been described previously.⁶

Importantly, our data suggest that this would reduce the risk for both the tackler and ball carrier, since it is the tackler who experiences the majority of head injuries, even during head-to-head impacts (78% of HIAs, table 3). Lowering the height of the tackle and increasing the number of bent at the waist tackler situations would prevent this highest propensity head contact from occurring. While impacts between the tackler's head and ball carrier's body would still occur, they carry significantly lower risk than head-to-head impacts. In particular, head-to-upper body (hip-to-shoulder) impacts carry low risk and may be advised as a focus for greatest tackler safety. These changes may protect both the tackler as well as the ball carrier.

Influence of speed, acceleration and direction on head injury risk

Confirming previous research,¹⁵ we also find that high-speed tackles and tackles where the tackler accelerates into contact are significantly more likely to cause HIA events, particularly when the tackler speed is high (figure 1). Of interest was that propensity decreases as ball carrier speed increases when the tackler is running at high speed, whereas it increases with ball carrier speed for static and low-speed tacklers (figure 1).

The reason for this pattern when the tackler is at high speeds requires future analysis. It is possible that an interaction of characteristics is responsible. For instance, as ball carrier speed increases when tacklers are at high speed, the likelihood of front-on and active shoulder tackles decreases, while side-on, angled and passive shoulder tackles are more numerous (data not shown). Since these tackle types and directions have a lower propensity (table 2), the resultant propensity for high tackler and ball carrier speeds may be lower compared with static or low-speed ball carriers.

High-impact force is another previously identified risk factor,¹⁵ which accounts for why front-on tackles and active shoulder tackles

have a higher propensity to cause HIA events than other tackler directions and types, respectively (table 1). This finding contradicts previous research showing that the injury rate per 1000 tackles was highest for tackles from behind and lowest for front-on tackles.⁶ However, that study examined all injury types, whereas Kemp *et al*⁵ studied concussions and found that tackling head-on was the factor most commonly associated with concussions.⁵

Appropriately targeted interventions and practical challenges

Interventions to reduce the overall incidence of head injury should be targeted towards those events described here and previously as having a high propensity to cause injury. Based on the present findings, the risk of HIA events would be reduced if the occurrence of those tackle characteristics shown to have a high propensity was reduced.

Practically, however, reducing the occurrence of certain of these events poses a significant challenge. One possible means to reduce speed would be law change to bring opposing players closer together by changing the offside line. This may, however, result in an increase in the number of situations where the tackler accelerates into the tackle to gain the speed with which to dominate the collision, a situation we have found to have a high propensity for injury, but which occurs relatively infrequently at present (table 2). Increasing the frequency of this situation might offset any reduction in speed at contact and increase the incidence of concussion.

The challenge for Rugby Union's regulatory authorities is to identify practically effective and viable, rather than theoretical, interventions. Practical approaches to risk reduction must focus on shifting player behaviours away from those events identified in this study as having a high propensity and towards low propensity scenarios, as might be achieved if upright tackles could be replaced with bent at the waist tackles. Law change or reinforcement of current laws to sanction undesired behaviours has been proposed to achieve this. Alternatively, the risk within each characteristic or behaviour might be reduced through education to ensure that the tackle is executed safely, and this requires further exploration.

An avenue that is worth exploring further is that of tackle technique, since it has been shown that poor technique is a risk factor for both concussion¹¹ and other injuries.²³ In considering technique, an important consideration for ultimate success is whether a technique is both safe and effective, because the latter will be a key requirement for coaches and players and must be acknowledged if an advised technique is to be adopted.

In this regard, some practical challenges exist, because evidence suggests that front-on shoulder tackles and tackles involving leg drive are most effective for success.²⁴ In the present study, we show that front-on tackles and tackles involving acceleration and speed, and thus higher energy transfer, are more injurious. The optimal technique for performance may thus be at odds with the optimal technique to reduce head injury risk, whereas poor tackle execution²³ may increase the risk. This balance of factors must be taken into consideration by future interventions focused on technique education.

An important consideration is that changing behaviour to reduce the risk of head injury may result in an increase in risk of other injuries. Quarrie and Hopkins⁶ recognised this when they found that all-injury risk to the tackler was highest for low tackles, and surmised that an increase in the proportion of low tackles might increase the risk of certain injuries to the tackler, even while reducing head injury risk. The potential undesired consequences of any behaviour changes must thus be monitored to allow rapid response to such potential negative outcomes.

What are the findings?

- ▶ This study is the largest to date to describe risk factors for head injuries requiring a head injury assessment in professional rugby union, using a cohort of 464 head injury events over 3 years.
- ▶ The tackler is more likely to sustain head injuries than the ball carrier.
- ▶ Energy transfer is a risk factor for head injury, since active shoulder, front-on, high-speed and acceleration into tackles were more likely to cause head injuries.
- ▶ We find that higher impacts are more than four times more likely to result in head injury. Tacklers sustain 78% of injuries, even when head-to-head contact occurs.
- ▶ Player body position is a significant risk factor, with an injury risk that is 1.5 times greater when tacklers and ball carriers are upright, rather than bent at the waist.
- ▶ Based on this study, World Rugby has proposed law changes and a global awareness programme to change player behaviour to lower the height of the tackle.
- ▶ These changes may reduce the risk of head injury on both the tackler and ball carrier.

How might it impact on clinical practice in the future?

- ▶ If successful, the law change will reduce the incidence of head injury events and thus concussions in professional rugby, with the hope that the effect filters down to all levels of the sport.
- ▶ This will provide a model for the application for the sequence of prevention model for reducing injury risk.
- ▶ Further monitoring is required to assess the effectiveness of the proposed law changes.

Study limitations

The limitations of the method of video analysis used in the present study have been described previously, as have the considerations around the use of HIA events rather than concussions to identify significant head injuries.⁷ Future research may compare time-loss concussions with HIA events to ascertain whether more severe head injuries, those diagnosed as concussions, differ from HIA events for any of the analysed characteristics.

Finally, the application of this research to the community game remains unknown. The incidence of concussion is lower in the community game than the currently analysed professional game, but its reduction is no less important. In principle, the introduction of laws should affect every level of rugby (although not equally), and the absence of specific data on the mechanism of head injury in community rugby means that it remains unknown what effect this law intervention may have on community rugby players. Further research is warranted in this regard.

In conclusion, this study examines the risk of HIA events associated with tackling, and finds that direction, speed, tackle type and acceleration all influence risk. Body position is a novel factor influencing risk, with upright tacklers and ball carriers representing a viable possible target for interventions to reduce the height of the tackle and thus the risk of high propensity head impacts. Based on these data, a group of experts from within the sport have recommended law amendments to change behaviour and reduce injury risk, with future possible interventions including tackle technique and further law changes.

Contributors RT, MR, MC and SK conceptualised the research study and its hypotheses. Data collection was performed by RT and BH. RT and MC performed analysis. The manuscript was written and edited by RT, MR, KQ, JB, GF, MC and SK.

Competing interests RT, MR are employed by World Rugby, the global governing body for the sport of Rugby Union. SK and MC are employed by the RFU, the governing body for Rugby Union in England. KQ is an employee of the NZRU, the governing body for the sport in New Zealand.

Patient consent Obtained.

Ethics approval World Rugby Internal Ethics Review Board.

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Risk factors for head injury events in professional rugby union: a video analysis of 464 head injury events to inform proposed injury prevention strategies

Ross Tucker, Martin Raftery, Simon Kemp, James Brown, Gordon Fuller, Ben Hester, Matthew Cross and Ken Quarrie

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